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New models for geoscience higher education in West Africa

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ABSTRACT

The challenges facing government-funded higher education institutions in West Africa in response to the demand for mineral resources require a spectrum of responses aligned with the multinational development programs. Efforts to meet the demands of industry and government organisations for skilled staff are undermined by the large numbers of students attracted to Earth Science courses in Africa. The African Union's African Mining Vision, the UN's Sustainable Development Goals and the New Education Model for Africa provide a framework for progress, however, there are only a few concrete examples that allow us to explore the strengths and limitations of different approaches. Two proactive initiatives based on locally-identified needs and that involve local and international collaborations are presented that allow such an analysis. The first, a public-private partnership entitled the West African Exploration Initiative (WAXI), provides graduate and professional training as a result of direct industry and partner government financial and in-kind support. The second initiative known as GEOLOOC is a new online training program supported by UNESCO and the International Mining for Development Centre that unites several West African universities in creating a common resource pool of Earth Science training materials. These activities are being carried out in collaboration with the local universities, and a new professional training centre based in Ouagadougou, Burkina Faso. In West Africa, by addressing locally-identified gaps in higher education delivery and by building local and international collaborations, the projects described here are starting to successfully implement new models to contribute to the enhancement of geoscience higher education. These new models complement existing government-funded Higher Education systems by providing them with much-needed support at a time of rapid change.

1. Introduction

Across Africa, mineral resources and mining accounts for more than 50% of the export revenues in more than 19 countries. In addition, oil and gas production underpins the economies of a further 9 countries. Within the West African sub-region, the economies of Burkina Faso, Ivory Coast, Ghana, Guinea, Niger, Nigeria, Mali, Mauritania, Togo and Sierra Leone are dependent on

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their sub-surface resources. Improvement in their socio-economic indicators including optimisation of mining practices and mitigation of the impacts of mining activities are thus partially reliant on the application of acquired knowledge in Earth Sciences at the tertiary level (Martínez-Frías, and Mogessie, 2012).

Despite the massive resource potential of the West African sub-region (Goldfarb and André-Mayer, 2017; Markwitz et al., 2016 and references therein), universities and government geological surveys of the 15 member states of ECOWAS (Economic Community of West African States) struggle with basic infrastructure to varying degrees, and find it difficult to attract meaningful funding (c.f., Saint, 2006). In spite of the potential economic impact of the minerals sector to the development of West Africa, in 2014, the Science, Technology, Engineering, and Mathematics (STEM) sector made up only 29% of all research in Sub-Saharan Africa (excluding South Africa, World Bank and Elsevier, 2014, see Table 1). In any case, the opportunities for academic studies are limited because the average tertiary enrolment rate for African countries is the lowest in the world at 6%, with significant differences between different groups: the ratio for Anglophone countries averages 6.7%, whereas that for Francophone nations is even lower at 2.9% (Onana et al., 2014).

Based on UNESCO/Geological Society of Africa data (Vasconcelos, 2009), there are currently 38 publicly funded higher education institutions that teach geoscience in West Africa (including Schools of Mines), although 29 are concentrated in Nigeria. Current national research priorities across Africa include a range of activities related to geoscience research, in particular Energy, Natural Resource Management and Information and Communications Technology (ICT, Table 1). However the low proportions of the Gross Domestic Product (GDP) spent on research in West Africa (often less than 1%) coupled with the overall low levels of GDP, mean that even as priority areas the available budgets are small.

The current state of universities in West Africa is best considered in the light of their post-colonial development (Lulat, 2005). The early period following independence was typically marked by the availability of a significant level of support for international scholarships for African students to study abroad, and many of the current senior lecturers in the universities benefited from these opportunities. As the population pressure increased, the focus of educational programmes shifted from higher education to prioritising primary and secondary education in order to overcome the extremely high illiteracy rates amongst the general population (>50% across West Africa for the period 1985–1994; World Bank Development Indicator Statistics). The resulting significant increase in student numbers placed pressure on resources and teaching staff. At the same time, from 1985 to 1989, 17% of the World Bank's worldwide education-sector spending was on higher education in West Africa, but from 1995 to 1999, the proportion allotted to higher education declined to just 7% (Banya and Elu, 2001; Bloom et al., 2006). This contrasted with the rest of the world where public financing of higher education in general kept pace with the increase in the number of higher education students. The increase in student numbers, commonly referred to as “massification”, is widely recognised as being one of the major barriers to higher education success in Africa at the current time (Clarence et al., 2014; Foley and Masingila, 2014; Hornsby and Osman, 2014; Mohamedbhai, 2014). Between 1995 and 2010, the total number of students enrolled in higher education institutions in Africa tripled (from 2.7 million in 1991 to 9.3 million in 2006), but expenditure on higher education only doubled. This situation was critical for countries with low incomes compared to the mean value for African countries. As a result, between 1991 and 2006 the ratio between the number of students and the increase in resources was 1.45 (World Bank, 2010).

In parallel, training was incorporated in the World Bank and in SYSMIN (System of Stabilisation of Export Earnings from Mining Products) technical assistance programs for the minerals sector, but these were largely focused towards development of the Ministries of Mines and geological surveys. Although data management and collection systems were modernised, the higher education institutions were not supported to develop appropriate courses that would allow these systems to be maintained. Two International Geological Programs have focused on the West African Craton: IGCP 485 “Cratons, metacratons and mobile belts; keys from the West African craton boundaries: Eburnian versus Pan-African signature, magmatic, tectonic and metallogenic implications” (Ennih and Liegeois, 2008) and the recently launched IGCP 638 program “Paleoproterozoic Birimian Geology for Sustainable Development”. These IGCP projects generally result in new research opportunities for graduate students, but are not directly aimed at supporting undergraduate programs.

In the last ten years, the African Union via the African Mining Vision (AMV), the Sustainable Development Goals, the World Bank and the African Development Bank have recognised the need for renewed investment in higher education to support the growing African population, which is predicted to have the world's largest labour force by the year 2040 (African Development Bank, 2014). These organisations recognise the need for a broader spectrum of higher education models to meet the demand for a skilled workforce that does not necessarily involve degree-based courses. The African Development Bank, UNESCO's Earth Science Initiative in Africa, the AMV and African Network of Earth Sciences Institutions (ANESI) share many proposals in terms of enhanced regional collaboration, better integration of the private sector and the minerals industry in particular via public-private partnerships (PPPs), and the use of ICT-based training programs as support for Africa's education needs (UNESCO, 2009; African Union Commission, 2011). There are more than 151 private higher education institutions in West Africa, but 139 of those institutions are concentrated in only 5 countries (Senegal, Ghana, Togo, Benin and Nigeria) (ADEA-WGHE-AAU-IIEP Policy Brief, 2009).

The AMV recognises the need for renewed investment in education in its action plan (African Union Commission, 2011) and states that critical success factors include the development of mutually beneficial partnerships between the state, the private sector, civil society, local communities and other stakeholders, as well as a comprehensive knowledge of its mineral endowment. The AMV Compact (AMDC, 2017) states as one of its principles:

States should raise relative levels of support for Science, Technology, Engineering and Mathematics (STEM), education to world standards to meet the demands for trained staff within government bodies and in industry.

Many models are being developed for the training of Earth Sciences in West Africa. Here we concentrate on two linked activities that are in a sense “experiments in higher education” that may be analysed in terms of their successes and failures, and then transferred to other sub-regions in Africa. The first activity, the AMIRA International West African Exploration Initiative (WAXI) is a long-standing PPP that provides graduate and professional training as a result of direct industry and partner government financial support. The only other geoscience PPP of this scale in Africa is the Africa Array program (Nyblade et al., 2011), whose initial geographic focus was southern and central Africa, the array now has three permanent stations in Nigeria and two in Ghana, with several in Ethiopa, with partner groups operating stations in Senegal, Mali, Algeria, Côte d’Ivoire and Morocco. Africa Array combines scientific research with ongoing training programs focussing primarily on seismic data acquisition and processing.

Table 1
National Research Priorities in Selected African Countries, highlighting areas in orange that are related to geoscience research. ICT = Information and Communications Technology. Compiled from country level reports associated with Mouton et al. (2014).

	Botswana	**Burkina Faso**	**Ivory Coast**	**Ethiopia**	**Kenya**	**Rwanda**	**Senegal**	**Tanzania**	**Zimbabwe**
Agriculture and food		Agriculture, Animal Husbandry	Agriculture (farming and food security)	Agriculture and agro-processing	Sustainable food, agriculture	Agriculture	Agriculture and agronomy	Agriculture	
Health	Infectious diseases	Health	Public health		Health		Health	Public health	Promoting and maintaining good health
Energy	**Energy for the future**			**Energy technology**		**Energy**	**Energy**	**Energy**	
Environment, resources		**Environmental challenges**	**Environment and biodiversity**	Water technology			**Environment**	**Natural resources**	**Sustainable environment and resource management**
Human and social sciences	Human sciences and policy research	Societal changes	Human sciences				Social science and humanities		Social science and humanities
Information and communication technology				**ICT**		**ICT**		**ICT**	
Engineering	Indigenous knowledge and technology systems		Engineering and technology	Materials technology			Mathematical and informatics	Biotechnology	
				Electronics and micro-electronics Chemical and pharmaceuticals Metals and metal products engineering biotechnology				Nano-technology	
Other		Urbanisation	**Natural sciences**			Manufacturing			National security of Zimbabwe

Table 2
Action items from the action plan of the African Mining Vision that are addressed by the GEOLOOC-WA and WAXI projects.

African Mining Vision Action Plan	WAXI	GEOLOOC-WA
Programme cluster 2 – Geological and mineral information systems • Support regional economic communities to: - adopt and implement sub-regional mapping and mineral inventory programmes including the use of modern remote sensing techniques. - scale-up efforts to standardise geological information management methods and approaches (e.g. stratigraphy, cadastre, legends, etc). - promote collaboration between the different national geological and mining related institutions (Ministries, Universities, Research Centres, etc).	- Integrated regional geological and geophysical mapping programs and development of new maps (Baratoux et al., 2011; Hein, 2010; Metelka et al., 2011; Perrouty et al., 2012; Tshibubudze et al., 2015; Block et al., 2015). - Mineral Atlas Monograph and other special volumes as online resources material (Markwitz et al., 2016). - Compilation of historical, geological, geographical and geophysical data in ArcGIS and MapInfo platforms.	- Development of online training material on remote-sensing techniques. - Joint development of training material at the sub-region scale, involving universities, research centres, and private sector.
Programme cluster 3 – Building human and institutional capacities - At national level: Diversify education, academic and professional training funding sources to include private sector; strengthen continuing professional development through short courses; align human resources development to AMV policy direction and needs of industry. - At sub-regional level: Establish strong inter-university collaborative programmes; improve cross-country accessibility of learning centres.	- Industry and government supported academic training at the postgraduate level with 55 current and completed MSc and PhD. - Training for academic staff. Collaborative agreements between universities, e.g, University of the Witwatersrand and Ecole Nationale d'Ingenieurs (Mali). - Research exchange programs for West African researchers to France, South Africa and Australia.	- Development of online training material meeting the needs of industry. - Diversification of funding sources for training. - Establishment of an inter-university collaborative program at the sub-region scale. - The use of internet improves cross-country access to the project outcomes.
Programme cluster 6 – Research and development - At national level: Improve funding for minerals research including focus on improved mineral extraction processes as well as environmental and social impacts. - At sub-regional and regional levels: Develop strategies to enhance collaboration between R & D centres with a view to knowledge-sharing and technology transfer; develop exchange of information networks to enhance exchange of data and good practices.	- Total research and scholarship funding to West and South African universities: $500,000. - Combined WAXI GIS available to all partner organisations. - Improved data access (Data Metallogenica).	- Strengthen a network of collaborators at sub-regional scale.
Programme cluster 8 – Linkages and diversification - At national level: Develop institutional arrangements that combine the minerals industry, trade and science, technology and innovation complexes. - At sub-regional and regional levels: Develop best practice on new institutional arrangements combining the minerals industry, trade and science, technology and innovation complexes for regional economic communities and member states.	- Annual meetings bringing together universities and geological survey organisations from partner countries across West Africa.	- Development of specific online training modules supporting the development of best practices for key players in the mining sector.

Since its inception in 2006 and before the AMV and the African Minerals Development Centre (AMDC) were developed, WAXI undertook activities that addressed several action items in four of the program clusters of the AMV action plan (see Discussion). WAXI established a long-standing partnership between West African and international academic partners, West African geological surveys and local private training centres such as Teng Tuuma Geoservices (TTG) in Burkina Faso.

The second linked activity is a new online training program, called GEOLOOC-WA. The program is supported by UNESCO and the International Mining for Development Centre (IM4DC) that is uniting West African universities to provide a common resource pool of Earth Science training materials to academics and students across the sub-region. It also addresses several of the action items in the program clusters of the AMV action plan (Table 2).

2. The WAXI public private partnership

The WAXI capacity building program is divided into two components, namely: (1) technical training and support, and (2) implementation and policy training. In stage 1 of the program, a gaps analysis was completed of local and international stakeholders (geological surveys, universities and mining companies) in order to establish research and capacity building needs. In stage 2 of the project, when the capacity building activities were fully funded by AusAID through AMIRA International, the capacity building work of WAXI consisted of student scholarships and research support, including financial support of geological survey personnel who attend training courses. Other capacity building activities include research management training, exploration training courses, a structural geophysics training manual, and access to Data Metallogenica (a global online encyclopaedia of ore deposits managed by AMIRA International, http://www.datametallogenica.com). In addition to the activities listed above, the IM4DC and WAXI personnel co-operated in delivering a five-week course in Burkina Faso on developing and maintaining GIS systems that host geological data. A new web-based IM4DC OpenData: Central Africa Geodata Information System was released and now provides governments, communities and industry with a tool to enhance management of natural resources (http://opendata.im4dc.org).

Although no formal monitoring mechanism was established at the start of the project for assessing the impact of the capacity building program, the career paths of WAXI-supported students are monitored, and feedback is collected from course participants (both university and geological survey personnel) to assess the level of skills learned and their impact on the individuals and the relevant organisation. This feedback indicates that personal development and growth of individual participants is seen as important for geological institutions to support new, and/or additional activities,

with students going on to have teaching roles in 10 different universities inside and outside Africa, and another 11 going into industry. A selection of testimonials that provide some insight on this can be found at the WAXI project site (http://www.tectonique.net/waxi3/?page_id=175).

The capacity building activities directly funded by WAXI are aimed at young geoscientists, university departments and geological surveys according to their primary roles. Related training sessions support these different groups according to their developmental requirements. The more than 90 postgraduate students supported so far by the WAXI project carry out a significant portion of the research, leading to publication in postgraduate theses. The results of the research program have been progressively published over the last ten years (see http://www.tectonique.net/waxi3 for a complete list of papers and access to the thesis collection), but in particular as four special issues that were compiled following the end of confidentiality for stage two of the project (Jessell and Liegeois, 2015; Jessell et al., 2016; Hein, 2016; and Goldfarb and André-Mayer, 2017). This research has so far resulted in 35 publications co-authored by African students and staff in international journals, and the research team continues to build on this list. Whilst not all students accessed funds directly from the project, they benefited from the intellectual and logistical support provided by the WAXI network of researchers. The WAXI-related scientific production represents more than 10% of publications over the last 5 years focussing on the geology of West Africa (Source: Web of Science for the period 2012–2017, Research area = Geology).

Twenty-five training courses have been delivered over the life of the WAXI partnership (fee-paying for company sponsors, and free to university and survey personnel). These courses were held in Ouagadougou, Dakar and Accra, however field excursions were held in rural Burkina Faso, Mali, Guinea, and Ghana. In total there were 80 days of training. Topics for these training courses were defined in collaboration with the West African geological surveys and company sponsors. The courses included: Analysis and interpretation of regional geophysical datasets (6 times); Applied mining geology held on mine sites (4 times); Exploration geochemistry (laboratory and field) (3 times); Field mapping (3 times); Exploration targeting in a business context (1 time); West African Ore Deposits (2 times); Regolith mapping (1 time).

Additionally, a course on science research management was developed and presented by key members of the WAXI research team in partnership with the TTG training centre of Ouagadougou, covering: ethics and professionalism; how to prepare proposals; budgeting and financial management; how to work with the mining sector; how to win sponsorship; how to deliver on time without losing your customer; training graduates for the mining sector; research relevance; business skills, planning and business focus.

3. GEOLOOC – geology open online courses

It is recognised that ICT solutions to massification provide a potential pathway to improve educational outcomes (Snowball, 2014). As indicated above, the teaching of geoscience subjects is sufficient to service the needs of the member states of ECOWAS as the contribution of mining and the extractive industries to national economic development continues to grow (Davies and Dareng, 2006). University teachers in West Africa are generally subject to enormous constraints when teaching geosciences, which demand mobility and finance for field training, analytical facilities and equipment. In addition, the scarcity of textbooks or standard sample sets available to describe the geological characteristics of the region creates a substantial obstacle to uptake of knowledge in the geosciences. In addition, the general inadequacy of national and international support systems has not made it possible for university professors to pool their resources even though they often work on similar problems.

Despite improvements of ICT infrastructures, the technological limitations of unstable internet access and low-speed connection has prevented effective use by universities of sophisticated online digital materials requiring high-speed connections (e.g., Massive Open Online courses offering high-resolution video streaming). Online material is generally available at no or limited cost, but it remains challenging to identify the most applicable resources for West Africa. This situation prevents an effective integration of online material in teaching practices at undergraduate and graduate levels. The linguistic barriers make the creation of regional training networks an additional challenge.

The “Geology Open Online Courses – West Africa” (GEOLOOC-WA, http://geolooc.net/) aims to contribute to the enhancement of knowledge-sharing in geosciences by building a regional training network with special emphasis on African geology and related topics including water resources, best practices for exploration and extraction of natural resources and minerals, environmental issues, and engineering geology. This initiative, from the outset, brought together academics from across West Africa and outside the region to identify the most important topics to be covered by the system, and the levels at which the materials should be aimed (primarily masters-level courses in the first instance). The GEOLOOC-WA action is able to augment the capacity of West African academics to provide quality graduate level courses that reflect modern geoscience thought, applied to and drawn from the specific geological problems found in the sub-region. It emphasises local content, based especially on Africa's geological and cultural legacy, whereas online material is being developed for low-to-moderate ADSL internet connections, typically encountered in large African cities (2–10 Mb/s). The development of a web portal for geosciences in West Africa is also facilitating the application of recent scientific advances to the local geological contexts, and hopefully will make the most talented students aware of the rapidly evolving frontiers in geosciences.

Of the 38 public Earth Science departments across the 230 universities in West Africa, most award some form of post-graduate degree and offer courses to both their own students and those from universities that do not have graduate programs. Whereas the action initially proposed in GEOLOOC-WA aims to be extended to all staff and students in West African Earth Science and Environmental departments, six universities have been identified as the first beneficiaries of this action. The choice is justified by several factors including: minimum required infrastructures; a well-established network of leaders in the major regional academic centres; and current political stability. The six institutions are: *Université Cheikh Anta Diop*, Dakar, Senegal; *Université de Ouagadougou*, Burkina Faso; the *University of Ghana*, Accra, Ghana; *Université des Sciences Techniques and Technologiques of Bamako*, Mali; *Ecole Supérieure des Mines et de la Géologie de Yamoussoukro* (ESMG), Ivory Coast; and the *Université Houphouët-Boigny* (UFHB), Cocody – Abidjan, Ivory Coast. One of these institutions, the Institut National Houmphouët Boigny including its *Ecole Supérieure des Mines et de la Géologie de Yamoussoukro* (ESMG) has been selected to become one of the 19 “Africa Higher Education Centers of Excellence » supported by the World Bank. Although this list does not cover all the West African countries with a strong mining focus, the project is open and any researchers interested in participating are welcome. In the future a means of financing new content may be required given the heavy teaching load imposed on most West African Academics.

The primary relevance of GEOLOOC-WA is based on the offer of courses contributing to enhance teaching facilities for graduates.

Furthermore, the collaborations developed could in the future underpin progress on the harmonisation of qualifications in geosciences. With enhanced skills in geosciences in general, graduates could establish meaningful careers and entrepreneurships in the mining, agriculture and water industries with qualifications that support the job market. The academic benefit of the GEOLOOC-WA action is that it directly addresses the academic needs of the region by increasing inter-institutional and intra-West African networking and by building regional capacity for effective and autonomous networking and training. It also contributes to the establishment of the 6 West African academic partners as international poles of attraction via their skills in the creation and delivery of Open Access Digital Materials.

Through existing partnerships, the GEOLOOC-WA action uses its strong links to incorporate its actions in an overall West African framework. These collaborations include ongoing industry and government funded research and training programs such as WAXI, or the T2GEM project (Geophysical and Geochemical Technologies for Mineral Exploration, based in Ivory Coast, https://t2gemci.wordpress.com and the African network of Earth Sciences Institutions (ANESI). These links provide important avenues for collaborative training via research in areas of direct economic impact to the member states, which will feed back into the GEOLOOC-WA action as case studies to be used in the course materials.

In summary, the primary objective of the GEOLOOC-WA action is to complement and improve the standards of teaching and learning of geology and geosciences in general. This is achieved through the development of online material in Earth Science by selected lecturers and researchers of West African Universities working in close collaboration with international experts in fields of research. Relevant topics are chosen with respect to geoscience challenges in West Africa, such as applied geophysics, regolith mapping, or mineralisation processes. The developed materials are progressively being made available on the GEOLOOC-WA platform (http://fad.geolooc.net/). This first platform is currently administered by the *Centre de Ressources Techniques et Pédagogiques* at the University Cheikh Anta Diop, Dakar, Senegal. Additional mirrors of this platform will be hosted at the University of Western Australia, at the Institut de Recherche pour le Développement (IRD) and at the University of Toulouse to enable higher traffic capacity. These and other partners are providing advice and expertise on the development of an online course in geology covering, in the first phase, five areas: Metallogeny and Mineral Resources; Sedimentology; Structural Geology; Rock Mechanics, Petrology and Geochemistry; Governance and International Conventions.

4. Discussion

4.1. WAXI and GEOLOOC in the context of international development program goals

The WAXI and GEOLOOC programs echo several of the overlapping proposals of the African Union's AMV, the UN's Sustainable Development Goals and the New Education Models for Africa (African Development Bank, 2014). In particular four AMV program clusters are addressed by these partnerships (see Table 2) including: 1) Geological and mineral information systems (program cluster 2) that has the goal to develop a comprehensive knowledge of Africa's mineral endowment; 2) Building human and institutional capacities (program cluster 2), and Research and Development (program cluster 6) that together create a knowledge driven mining sector as a cornerstone of an internationally competitive African industrial economy; and 3) Linkages and diversification (program cluster 8) aimed at development of policies and strategies that leverage mineral extraction and processing operations into broader economic development outcomes.

New models for education in Africa are being proposed by the African Development Bank (2014). Similarly there is renewed interest from the World Bank for renovation of the African higher education system (World Bank, 2014). The Africa Development Bank New Education model for Africa (NEMA) proposes driving skills development through six key components, four of which are also directly addressed by the WAXI, GEOLOOC-WA and TTG

Table 3
The 6 key-components of the Africa Development Bank New Education model for Africa (NEMA) addressed by the WAXI/TTG Partnerships and GEOLOOC-WA program.

New Education Model for Africa	WAXI/TTG Partnerships	GEOLOOC-WA
Link with the labor market	The WAXI partnerships include both industry and government partners so that the end user of the education system can provide input into course content.	Development of courses focusing on the mining codes in West Africa
Public-private partnerships help regional member countries tap into the experience, knowledge and financial leverage of the private sector to develop cutting-edge learning environments	The WAXI capacity building program is industry funded, but supports training for African public body personnel.	
Developing creativity and critical thinking: Move away from a purely classroom-based education model to foster interaction and debate among professors, students, young entrepreneurs and businesses in Africa and globally with a view to create a culture of entrepreneurship and job-rich growth.	The TTG/WAXI partnership brings together industry and government personnel in classroom and field training scenarios and seeks to inspire young West Africans to entrepreneurship in exploration, mining, beneficiation, and business development in the minerals sector.	Develop self-learning capacities, and modification of the classical teacher – student model. Develop critical thinking through guided use of multiple internet resources.
Participation: Engage key stakeholders in developing strong education models (parents, faculties, universities, science academies, nongovernmental organisations, civil society and communities).	Training and higher degree programs produce quality accredited research graduates.	
Evidence-based. Ensure that all programs have a built-in impact evaluation component to ensure that they are results-based, focusing on quality and learning outcomes.	Educational outcomes are monitored to establish the long-term employment activities of students.	Possible implementation of tools to monitor student activity, progress, and impact of the online training program on acquisition of knowledge.
ICT-based: Provide high-quality education and tap into new learning technologies	High-quality education through international partnership and involvement of scientific leaders in their respective fields of research.	The GEOLOOC-WA program provides the first online course support platform in West Africa for geoscience. When fully engaged, this program will help with the training of an increasing number of students in African universities.

Table 4
Three key themes of the UN's Sustainable Development Goals addressed by the WAXI/TTG Partnership.

SDG Targets	WAXI activities
Goal 4 Quality Education • By 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship • By 2020, substantially expand globally the number of scholarships available to developing countries, in particular for enrolment in higher education.	• WAXI brings together 10 West African geological surveys and 5 West African Universities in a single research program • WAXI Industry Sponsors directly fund training courses that are open to geological surveys and university personnel at no cost • WAXI provides Research Management as well as technical training courses • The WAXI Capacity Building program has supported over 40 PhD, Masters and Honours projects for African students
Goal 9 Industry, Innovation and Infrastructure • Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries, in particular developing countries.	• WAXI brings together 10 West African geological surveys and 5 West African Universities in a single research program • WAXI Industry Sponsors directly fund training courses that are open to geological surveys and university personnel at no cost
Goal 12: Ensure sustainable consumption and production patterns • Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production	• WAXI provides Research Management as well as technical training courses • The WAXI Capacity Building program has supported over 40 PhD, Masters and Honours projects for African students
Goal 17 Partnerships for the Goals • Mobilize additional financial resources for developing countries from multiple sources • Enhance North-South, South-South and triangular regional and international cooperation on and access to science, technology and innovation and enhance knowledge sharing on mutually agreed terms • Enhance international support for implementing effective and targeted capacity-building in developing countries to support national plans to implement all the sustainable development goals, including through North-South, South-South and triangular cooperation • Enhance the global partnership for sustainable development, complemented by multi-stakeholder partnerships that mobilize and share knowledge, expertise, technology and financial resources • Encourage and promote effective public, public-private and civil society partnerships, building on the experience and resourcing strategies of partnerships	• The WAXI GIS now contains over 600 Gb of exploration geoscience data, and is made available to all partner geological surveys and universities in West Africa • The WAXI training courses are open to all government agencies and industry personnel • The WAXI program funds an annual one-day forum of West African Geological Surveys, and has organised two international conferences on West African geoscience (Ouagadougou in 2007; Dakar in 2015) • WAXI sponsors an annual research meeting that brings together research partners from across West Africa • The WAXI GIS uses modern WMS technology to provide data access to all partners • The WAXI program combines public and private higher education facilities, geological surveys, NGOs and the mining industry to provide a regional network that is building a new level of collaborative research and training across West Africa

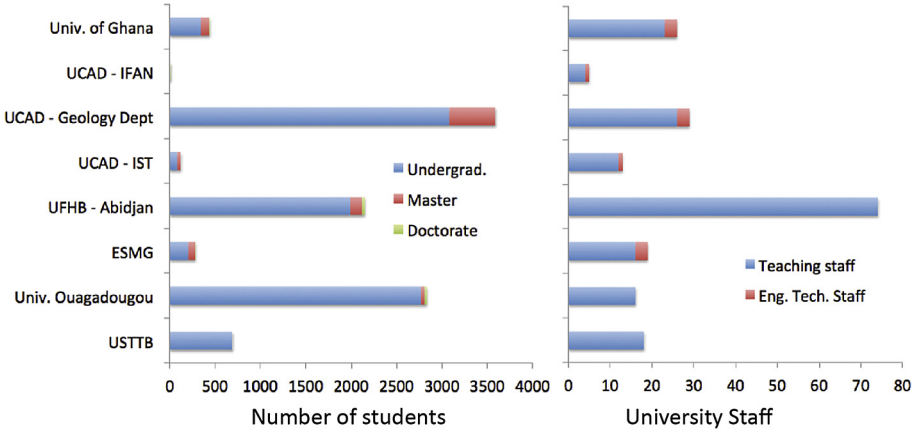

Fig. 1. Comparative charts of the disparity of the distribution of staff and students from several West African universities in geosciences. Left: number of registered students in each institution which returned their survey in 2014. Right: number of academic employees in each geoscience department by category (UCAD = Université Cheikh Anta Diop, Dakar, Senegal; IST = Institut des Sciences de la Terre, Dakar, Senegal; UFBH = Université Félix Houmphouët-Boigny, Abidjan, Ivory Coast; ESMG = Ecole Supérieure des Mines et de la Géologie, Yamoussoukro, Ivory Coast; USTTB = Université des Sciences Technologiques et Techniques de Bamako, Mali).

partnerships (Table 3). Finally we can map WAXI activities to the UN's Sustainable Development Goals (Table 4).

4.2. Meeting challenges faced by the West African higher education sector

It was noted in a recent publication of the World Bank and Elsevier (2014) that sub-Saharan African (SSA) research outputs have been growing in quantity and quality, with the largest growth in the health sector. The reason for the improvement in SSA's research capacity in the health sciences is the result of persistent support and funding from development partners and governments. A corollary of this is that when strong attention is paid to local needs and when appropriate initiatives are implemented, the likelihood of improving capacity, experience and ultimately quality outputs rises. The WAXI project has largely focused attention on the needs of the minerals industry, the local geoscience agencies and universities in West Africa, but cannot currently meet the demand from students who will need further support, both endorsement and sponsorship, from governments, regional political bodies, international agencies and industry to meet their demand. Unfortunately, there is a degree of suspicion amongst international aid agencies when private industry involvements are proposed in capacity building exercises, something that can be best addressed by demonstrating the value of these partnerships. WAXI is already helping to bring about intra- and inter-regional collaborations

through its work involving joint field research and the mentoring of earth scientists. The GEOLOOC online training platform is also strengthening international collaborations and regional awareness of training needs. The short-term impacts of these activities result in trained students and research funds for West African departments, longer-term effects such as the impact on the migration of experts is not yet known. One of the challenges for online training is the continued resources needed to maintain and renew materials, and the significant financial and time barriers to producing new content. No obvious mechanism for continued support exists at the present time.

West African universities are characterised by wide disparities in capacity and infrastructure, as revealed in a 2014 survey conducted in the framework of the GEOLOOC-WA project (Fig. 1). These disparities encompass all aspects of academic teaching and research, including the number of permanent staff, professors, technical staff, and ICT support. A platform to deliver undergraduate online materials to registered students is already available in Dakar (Université Virtuelle du Sénégal) and Accra in various fields of teaching (but not the geosciences), whereas internet access in Mali is less stable and slower than in other ECOWAS countries which limits the usefulness of such initiatives (for the time being). The number of students studying geology are also extremely variable with 3524 students at the geology department of University Cheikh Anta Diop, 658 at Bamako, and less than 300 students in some institutions (Institut des Sciences de la Terre de l'Université Cheikh Anta Diop, Dakar, Senegal, Ecole Supérieure des Mines et de la Géologie de Yamoussoukro, Ivory Coast). In addition to these disparities, there is the language barrier between English-speaking and French-speaking countries in West Africa, with every country in West Africa sharing at least one frontier with a neighbour that uses another administrative language. Europe has an even more diverse language pool, however it is probably this extreme diversity that helps, because no one's language dominates, whereas in West Africa the division between Anglophone and Francophone countries means that each grouping has a critical mass that allows them to work independently. New models for education in geoscience could focus on reducing these disparities by a more efficient pooling of resources, by more regular exchanges and visits between the West African universities, by providing specific opportunities to the weakest academic centres, and by stimulating the use of English for lectures and scientific exchanges in French-speaking countries, as in terms of volume the availability of English-language educational materials is much greater. Finally, the uptake and outcomes of ICT approaches suggest that there is still significant fine-tuning that needs to be done to assure optimal educational outcomes (Rohleder et al., 2008).

There is a generational change likely to occur in many institutes in the next 10 years as a wave of students who benefited from scholarships in the 1970's and 1980's reach retirement age. Consequently, there is a short term need to provide PhD opportunities to meet the coming skill shortage. The WAXI PhD bursaries can continue their career within West African academic institutions as researchers and lecturers, with increased mobility possible between West African universities as a result of enhanced networks.

Currently there is a large disconnect between the skills of graduates and the needs of the labor market. The number of university graduates tripled in Sub-Saharan Africa over 1999–2009, from 1.6 million to 4.9 million. Youth unemployment for young adults with pre-tertiary education stands at 60–70%, and drops to 40% with at least one year of Tertiary education (Agence Française de Développement and the World Bank, 2014), but still indicates a real need to realign educational priorities with the market. Professional training provides the critical support needed to complete academic education delivered by universities. Training centers such as TTG have this objective and are meeting the growing demand for a shift from technical and vocational education and training to skills development (Afeti and Adubra, 2014).

The African Union's recently published outlook on education report (2014) emphasises that most African universities are predominantly teaching institutions rather than research institutions. Given the limited budgets of national governments, and the likelihood that there will be no short-term financial relief for Education Ministries across Africa, coupled with need to meet the demands of primary and secondary education, it is unlikely that research capacity will be significantly improved by direct government support in the near future. Alternative models, such as WAXI and others, will therefore continue to provide much needed access to funds and equipment for African researchers.

4.3. Responding to the "brain drain"

The loss of skilled researchers from West African higher education institutions stems from two sources: the loss of academics to industry, and their loss to overseas (extra-African) universities. In both cases the attractiveness of working for a wealthier organisation comes from significantly higher salaries and better access to equipment. In the WAXI project the split is about 50:50 between research students that continue in academia and those that go into industry. In the case of mining companies, this is not unique to Africa and the employee may in fact stay in their home region or country, so the challenge is for academic institutions to engage with industry and leverage their presence via research and training partnerships. In addition placing well-trained Africans in mining companies provides the opportunity of them to take on senior roles that in the long term are of benefit to the region, so taking a broader development view we shouldn't necessarily see these as a "loss". The WAXI project provides a platform for regional collaboration, however country-level projects are also possible. Similarly the African diaspora provides opportunities for Africans working in extra-African institutions to access research funds that are not otherwise available, and to train African students. This of course probably increases the possibility that the students do not return to their home country after their studies, however these questions are always a balance between national and personal benefit.

The African Union's Agenda 2063 (African Union, 2014) includes a call for "African resources to finance its development", and for a partnership of governments, businesses and philanthropists to establish an African Science Technology and Innovation Fund, and as has already been discussed, the increased support of STEM is widely recognised as an important step towards improving the attractiveness of the universities to young scientists.

4.4. Long-term sustainability of projects

The sustainability of projects in developing countries is always a challenge, as most programs are time-limited, and do not have built-in sustainability mechanisms. This is particularly true of technology intensive activities, as it does not matter how well trained personnel are if the costs of continuing technical support for equipment is not foreseen. Although this is a problem that is far from being unique to Africa, the ability to cross-finance equipment costs are much more restricted there.

The WAXI program, like Africa Array, is a PPP, with funding predominantly coming from the international mining sector. While this might at first sight seem a fragile funding model, as commitments are rarely made by companies for more than 3 years, in both cases they have managed to continue for more than a decade even through a major industry downturn. The sustainability of these PPPs has come in part from the recognition that although the

partner organisations have different drivers, they share common interests in improving the research capacity and knowledge base for Africa.

The GEOLOOC project started with seed funding from UNESCO, and the future challenge will be to find funds that provide the resources for African academics to create local content. The effort required to make quality online materials is often underestimated, and should be thought of as equivalent to writing a text book (rather than simply being the equivalent to developing a course). One possibility is to encourage universities and CAMES (African and Malgach Council for Higher Education) to recognise the value of this additional work-load when considering promotions, which would increase the incentive for academics to devote time to this type of project. Additional funding mechanisms are also needed to allow sabbaticals focussed on developing new online materials, as the workload of academics does not allow them the time to learn the skills needed to develop online content, or actually create it. An efficient use of funds might be to have intensive training courses that simultaneously train people in developing content, and providing the resources to do so.

5. Conclusions

The challenge of massification in higher education in Africa is not unique to schools of Earth Sciences, however the opportunities to find appropriate responses varies according to subject area. The importance of the minerals sector to the economy of African states, combined with the recognition of the importance of well-trained geologists to the international minerals industry has created the opportunity for new models of industry-supported graduate-level research and training programs in West Africa. At the undergraduate level, a parallel effort of a university network producing online training materials has also been initiated. Together these initiatives provide additional models for higher education and research in countries where competition for meagre national budgets have not allowed higher education institutions to achieve the standards needed to meet student and industry demands.

The projects described here may be considered as experimental case studies of attempts to implement the different visions for educational development in Africa. The major actors in African geoscience higher education have recognised that a focus on the short-term needs of a country provided by support for governance and data acquisition aspects of the minerals sector is clearly required, especially since over the last ten years renewed exploration activity and changes to governance regimes have significantly increased West Africa's attractiveness to the minerals industry. Sustainable development projects that provide long-term benefits through supporting higher education institutions and exploring new models for technical and vocational skills development in geosciences will enable these countries to face the challenge of a growing demand of qualified geologists for industry and geological surveys, as well as for teaching and research activities at the universities. In West Africa, by addressing locally-identified gaps in higher education delivery and by building local and international collaborations, the WAXI-GEOLOOC-TTG partnerships are starting to successfully implement complementary delivery models to contribute to the enhancement of geoscience higher education.

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